AUG 4 2005

Society of Fire Protection Engineers

August 4, 2005

Dr. Shyam Sunder
Deputy Director
Building and Fire Research Laboratory
National Institute of Standards and Technology
100 Bureau Drive
Gaithersburg, MD 20899

Dear Dr. Sunder:

We appreciate the opportunity to review and comment upon the draft "Final Report of the National Construction Safety Team on the Collapses of the World Trade Center Towers." The Society of Fire Protection Engineers fully supports recommendation #28, which states:

> "NIST recommends that the role of the 'Design Professional in Responsible Charge' should be clarified to ensure that: (1) all appropriate design professionals (including, e.g., the fire protection engineer) are part of the design team providing the standard of care when designing buildings employing innovative or unusual fire safety systems, and (2) all appropriate design professionals (including, e.g., the structural engineer and the fire protection engineer) are part of the design team providing the standard of care when designing the structure to resist fires, in buildings that employ innovative or unusual structural and fire safety systems."

Fire protection engineers, as well as engineers of other disciplines, bring unique strengths to the design process. Fire protection engineers are the only design professionals that have a detailed understanding of fire, how fire impacts people and buildings, how fire protection technologies can be used to protect people and property, and how to integrate fire protection systems with other building features.

Just as specialized expertise is needed to design innovative or unusual buildings, the same specialized expertise is required to determine what constitutes an "innovative" or "unusual" design. For fire protection design, only fire protection engineers bring the required expertise to determine if a traditional, prescriptive design approach is suitable or if more in-depth analysis is required. It is our position that all engineering designs should be prepared under the supervision of the appropriate type of engineer (e.g., fire protection, structural, etc.), and we would suggest that recommendation #28 be expanded accordingly.

In the case of structural fire resistance design, the current prescriptive design techniques do not require an analysis of fire behavior, heat transfer, and structural response. While this design

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approach has served society well for quite some time, it may not be suitable in all design situations. Moreover, the current prescriptive structural fire resistance design techniques are frequently applied by professionals who have limited or no training or experience in fire behavior and who may not recognize circumstances where more in-depth analysis is required. Combining the strengths of fire protection engineers and structural engineers in the design of structural fire resistance brings a number of advantages. These include:

- Understanding the damage that could result in the case of fire
- Ensuring that the structure can respond to the fire conditions to which it may be subjected
- Providing fire resistance commensurate with stated design goals for a structure

We have assembled a team of over 20 of the world's leading fire protection engineers with a goal of providing NIST with constructive feedback. Comments developed by our review team are attached in the appendix to this letter.

We would suggest that many of the problems that are addressed in your recommendations are international in scope. Therefore, we would recommend international collaboration in development of solutions to these problems.

Please note that due to the volume of the draft report (~10,000 pages) and the brevity of the public review period (six weeks), we were not able to review the entire report. Therefore, tacit agreement should not be inferred where we did not comment. Similarly, our submission of comments does not imply that we have "peer reviewed" the report.

Thank you again for the opportunity to review the draft report. We would be happy to provide additional detail regarding the contents of this letter or the appendix should you desire.

Sincerely,

For Samuel S. Dannaway, P.E.
President

General Comments

1. There seems to have been little or no attempt to compare findings and results with other published work. Additionally, any information that was derived from published literature should be properly referenced.

2. Differences were found in performance for similar assemblies tested in different furnaces (ULC and ULN). We recommend that NIST examine the reason for this further. To be comparable between tests (repeatability) and comparable among all tests (reproducibility), and to provide data for analytical methods, fire resistance test methods should include a requirement for specification, measurement, and reporting of furnace heat flux. Heat flux measurements are required in ASTM E-1529 but not in ASTM E-119 and standards similar to ASTM E-119.

3. Having heard comments at briefings by NIST that a "code review" was not conducted as part of this study, it's inappropriate for NIST to make comments that the building met code. Either a code review should be conducted, with any/all deficiencies reported, or the report should be silent on the issue. As is, statements that the building met code have no technical basis.

4. Use of the word "conservative" needs to be defined in the context of a forensic study that usually is interested in replicating "what happened", rather than be conservative in the sense of an analysis for a design in order to implicitly include a factor of safety.

5. Each of the Recommendations, and their supporting text, should be revised based on their risk-significance and cost-benefit.

   NCSTAR 1 and other NIST reports related to the WTC incidents do not indicate the level of risk reduction to be derived or the benefit to be gained by implementing the recommendations based on the cost to implement the recommendations.

   Executive Order 12866 requires that federal agencies consider cost and benefit in changes to regulations. Agencies must consider the degree and nature of risks to assure that regulations are cost-effective. In assessing costs and benefits, agencies must assure that regulations impose the least burden on society taking into account the consequences and costs of intended regulations.

   It is recognized that NIST is not implementing any regulations with the recommendations in NCSTAR 1, but it is clear that NIST is recommending changes in regulations that, if implemented, will likely result in significant societal costs. Neither the costs to implement nor the reduction in risk to the public have been identified, quantified, or analyzed.

   While NIST may not be subject to E.O. 12866 because it is not implementing any regulations, NIST is recommending the implementation of recommendations to change regulations or create new regulations at some levels. Section 9 of Public Law 107-231, National Construction Safety Act, states that NIST shall promote the adoption by the Federal Government of the recommendations for specific improvements to building standards, codes, and practices. The intent of E.O. 12866 for cost-benefit analysis of significant regulations should be followed. Irrespective of the Executive Order, cost-benefit analysis and risk significance information from NIST are necessary to support the recommendations and to assist standards-making organizations in making informed decisions to implement the recommendations in codes and standards.

While it might be possible to implement the recommendations, it is not clear that it is necessary to implement the recommendations based on their cost-effectiveness, risk-effectiveness, response to credible risks, need for implementation for all tall or low-rise buildings, and their overall societal impact.

Comments on NCSTAR 1

Location	Comment
Page xliv, 1st full bullet on page	In last sentence, which compares differences in failures between WTC 1 and 2, shouldn't there be some mention of the 'eccentricity' caused as a result of damage in one structure being predominantly on one side, while the other had damage nominally in the middle?
Page 5, footnote	The style adopted for this report is unacceptable for a technical report. Without references, it is impossible to understand the basis for a particular comment, whether from fact, eyewitness observation, simulation, expert judgment or an assumption. The lack of citations weakens the report, since the basis for statements requires a substantial expenditure of effort of pouring through hundreds of other pages to identify the source for a particular comment.
Page 12, 3rd sent. of 2nd para under Figure 1-8	This construction is not so commonly regarded. Type X gypsum is needed (or type C), not any type of gypsum wallboard. Further, this assembly is only regarded as being fire resistant if it is properly constructed per a listed design.
Page 8	It is noted that structural steel with yield stresses ranging from 36 to 100 ksi were used. Typically with very high strength steels, there is little variation between yield and tensile failure and maximum yield stresses which are well below the reported yield stress are used in the design to prevent brittle failure (for example F_U = 82 ksi, F_Y = 80 ksi; use F_Y = 60 ksi in design). This would have resulted in larger members with more capacity vs. that in which the full F_Y was used. Was this done in the WTC design, and if not, could it have been a factor?
Page 12	What is the basis for the estimate of automatic sprinkler being capable of controlling a fire of 4,500 ft^2? The design area of the sprinklers should be cited, if any specific area is to be identified. Insight into the basis for this comment appears on p. 24 (last paragraph) to indicate 1,500 ft^2 is attributable to sprinklers (was this the design area?) and then an estimate of the capability being to triple this amount. The noted factor of 3 is not supported in any technical reference in the literature and appears arbitrary. These rough estimates should be clearly identified, so as to appreciate which comments are based on such rough (arbitrary?) estimates and when comments have a strong basis.
Page 15, 1st para	Additional code deficiencies with the egress system include the absence of stairs discharging directly to the outside. In the case of WTC 1 and 2, all stairs discharged within the building.
p. 25, 1st para, 4th sent	While it may be true, this sentence is pure conjecture. It adds nothing to the paragraph and should be removed.
Page 29	"At temperatures above 500° C, the steel <u>further</u> weakens, …" Add the word further to clarify that it has already started to weaken prior.
Page 31, Figure 2-11	A label or improved caption is needed to understand what this figure is indicating or what is the orientation of the diagram (i.e. is it a plan view, cross-section, etc.).

Page 117, sect 6.9.3, 2nd sent., 4th para	Use of the word "conservative" needs to be defined in the context of a forensic study that usually is interested in replicating "what happened", rather than be conservative in the sense of an analysis for a design in order to implicitly include a factor of safety.
Page 118, section 6.10	The University of Maryland Department of Fire Protection Engineering has performed reduced-scale modeling of the fires in the WTC buildings. Although not published in the open literature, a report on this work and its findings is available from UMD. Since the scale modeling yielded different results, we recommend the NIST investigators analyze the UMD work and attempt to resolve or explain any differences in findings.
Page 124, table 6-6	"Rubblized"? Surely, there must be an existing word that can be used rather than transforming the noun "rubble" into a verb.
Page 131, 2nd bullet	We suggest referencing Jeanes' paper (SFPE Technology Report 84-1, 1984) for this data. Jeanes' data was acquired while a Research Fellow at NIST.
Page 144, 1st bullet after "The four cases…"	If 2,000 to 3,000 gal of jet fuel was ignited in fireballs outside of the building, and only 10,000 gal was introduced into the building by the aircraft, then how did all 10,000 gal ignite hundreds of workstations?
Page 175, section 8.3.1	Quintiere et al. (*Fire Safety J.*, 2002) have published an alternate theory of the collapse mechanism for the WTC buildings. Has the investigation team considered this scenario?
Page 195, bullets under 8.6.2	This is a general wish list, without any analysis as to the effectiveness and reliability of these factors for this particular incident. We suggest either deleting this list or providing such analysis
Page 204, Rec. 4	Delete "(especially for tall buildings greater than 20 stories in height)." There is no technical basis for establishing a threshold of 20 stories in height. If it is important to evaluate and establish technical bases for construction classification and fire rating requirements for buildings, it is likely important for buildings of heights less than 20 stories.
Page 204, Rec. 4, footnote #21	Delete "which were originally developed for buildings with less than 20 stories in height" in the second sentence. Also, delete the word, "generally" in the second sentence and the last three sentences. There is no technical basis for establishing a threshold of 20 stories in height. There is no technical evidence presented in the NIST WTC reports that fire resistance rating requirements developed for buildings less than 20 stories are inappropriate for buildings greater than 20 stories. The use of the descriptor, "generally" makes this a very vague statement. The statement in this footnote that there is "considerable conservatism in those requirements" indicates that the requirements are adequate for safety and that requirements that have "generally decreased" are not insufficient. The statement that consequences to occupants on upper floors (20 stories and above) is a generality which is unsupported. Depending on specific circumstances, occupants on lower floors could be more severely impacted by

	a given fire than those on upper floors.
Page 204, Rec. 4	Add a footnote to Bullet No. 4 as follows: "A Maximum Credible Fire Scenario includes conditions that can be reasonably anticipated related to building construction, occupancy and fire loads, ignition sources, compartment geometry, fire control methods, and similar factors as well as reasonably anticipated adverse conditions. A Maximum Credible Fire Scenario does not include highly unlikely, although possible, events or combinations of events." In bullet No. 6, replace "unusually large" with "large but reasonably credible"
Page 206, Rec. 6	Based on this study, does NIST have any recommendations for either minimum recommended densities, or the loads and impacting geometry used in impact testing for SFRM?
Page 207, Rec. 7	Generally, the when the term "structural frame" is used in the context of structural fire resistance, it is used to mean that the frame behavior of the structure is analyzed under conditions of elevated temperatures. It is noteworthy that doing so requires conducting a performance-based design that consists of three steps: (1) estimation of fire boundary conditions, (2) calculation of thermal response to the fire boundary conditions, and (3) estimation of structural response. Is it intended by this comment that this type of analysis should be performed? If so, this should be clarified. If the comment is intended to apply to the current prescriptive approach to structural fire resistance design, codes presently require that primary horizontal members such as girders, beams and trusses that have direct connection to columns (and thereby provide lateral support to the columns), have the same fire resistance rating as the columns. However, the floor construction, including secondary beams and joists, often require one hour less fire resistance, as was the case in WTC. When exposed to fire, primary steel horizontal members will sag considerably (even with adequate SFRM) and can create large lateral loads on columns, as opposed to provide resistance. Particularly in the case of exterior columns and beams perpendicular to exterior walls, there is no similar structural member on the opposite side of the column to provide resistance. This can result in the exterior columns pulling in, which was reported to have happened with WTC 1 and 2. Floors can act in compression to provide resistance to lateral forces, and had the floors and secondary framing been designed for 3 hours fire resistance also, columns may have remained stable longer. This recommendation should be modified to recommend that floors and secondary structural members have the same fire resistance rating as the columns.
Page 207, rec #8	Delete "tall" in the second sentence and add "required by the building code to have a fire resistance rating" at the end of the sentence. The need for a building to sustain burnout without collapse is not unique to tall buildings. It is not necessary that all buildings be capable of sustaining burnout without collapse. Small or inconsequential buildings of ordinary construction need not be required to sustain burnout without collapse. The societal need for some buildings to sustain burnout without collapse will be reflected in the model

	buildings codes. Thus, the recommendation should be addressed toward those buildings for which the building code requires fire resistant structural ratings.
Page 207, rec #8 & page 208, rec #9	The proper designation of "ASCE 29" is ASCE/SFPE 29.
Page 207, Rec. 9	We would note that the Society of Fire Protection Engineers has already begun the development of guides and standards to facilitate the performance-based design of structural fire resistance. Specifically, we have published a guide on determining fire boundary conditions for purpose of structural analysis, and we are presently developing a standard in the same area. However, standards on thermal response calculation and structural response calculation are still needed.
Page 208, Rec. 10	The development of new fire resistive coating materials for enhanced performance and durability is proposed. Comment should be made on the use or acceptability of reinforced concrete encasement for steel columns as an alternative to wraps or coatings.
Page 209, Rec. 12	It is unclear what is meant by "redundancy of active fire protection systems." Is it meant that additional, redundant systems should be provided, or that additional redundancy should be built into the systems that are already required?
Page 218, Rec. 30	It is noteworthy that the Society of Fire Protection Engineers presently has two short courses on computational fluid dynamics modeling. These were developed for classroom delivery, but they could be converted to a distance-learning format.

Comments on NCSTAR 1-6

Location	Comment
General	It is very difficult to find out what fires were used for analyzing the various components and subsystems. Reference is often made to Project 5, which is an excellent summary of what was done, but it does not clearly state what went into Project 6. Some sections used a ramped up temperature with no cooling phase, and others used the very detailed output from Project 5, with fires of different temperatures moving about each of the fire-affected floors. Summaries of fire exposure are given in various places, the best perhaps buried in Appendix A to the Global Structural Analysis supporting technical report. There may be other locations where it is better described, but like so much else it is very difficult to find. This is one aspect which will make it difficult for others to check and validate the structural analysis results at a later date.
General	The comments on fire testing and some of the structural analyses give insufficient consideration to the expected structural behavior during the cooling phase of the fire. This is a particular problem where high levels of axial restraint cause large tensile forces to develop in beams and slabs as the fire goes out and the floors contract on cooling. The effect of the cooling phase is mentioned in Figure E-11 but not elsewhere in the Executive Summary or Recommendations of Project 6. The discussion of fire resistance testing should address this issue because it is ignored in standard testing procedures (ASTM E119).
p. l (note 'L', not one), footnote	What is the basis for assuming that the adherence of concrete to a steel member is the same as that for the CAFCO product (or any other material)? With the lack of any data to compare the adherence characteristics of these two materials, using the performance of the concrete is inappropriate.
p. lxx, 2nd bullet	Instead of saying that there was "effectively no wind" – why not say what it was, i.e. 10 mph and then conclude it was negligible?
p. lxxii, finding 11	More explanation is needed as to why the unexposed surface temperatures are so different to result in a 30 minute difference in fire resistance. In terms of the unexposed surface temperature measurement, the tests with the 17 and 35 ft spans should have been very similar except for the size of the furnace.
p. lxxiii, finding 14, last sentence	Given the well-known importance of moisture content of concrete on fire resistance, if the noted appreciable differences in performance are attributable to a difference in moisture content, it begs the question as to how such was monitored prior to the test to confirm that the test would be representative, i.e. a valid comparison with other samples.
p. lxxiii, finding 18	Was there any photographic evidence of the large deformations and buckling of the spandrels? Given the reliance of the photographic

	evidence to confirm the accuracy of the modeling, this predicted behavior would seem to be noteworthy and worthy of confirmation via the photographs. If it's not present in the photographs, doesn't that question the validity of this calculated result?
p. lxxiv, finding 22	Define "conservative".
p. 17, last sentence	What tests are referred to here? These tests should be described and identified. Did they follow a standard protocol or an ad-hoc method? Also, define "slightly better". Why can't the definitive comparison (e.g. 5%) be presented? Further, how (i.e. relative to what performance characteristics) was the material better?
p. 19, 2.2.7, 1st para	The upgrades were only provided on the floors identified? Granted, these are the only ones relevant to this study, but the statement doesn't provide that caveat. On p. 24, 18 floors in WTC 1 and 13 floors of WTC 2 are identified as have been completed. The two statements should be consistent.
p. 22, Table 2-1	NCSTAR 1, p. 12, indicates that the term "fireproofing" will not be used in that report, given the implication of performance provided by this term. Why is it ok to use the term in NCSTAR 1-6 and not NCSTAR 1?
p. 24, 2nd sent., 3rd para.	Being that the measurements are so much different than that obtained from the interpretation of photos, why is there so much error associated with the photo analysis? This wouldn't be such a significant issue if so much weight wasn't placed on visual and photographic evidence being used to calibrate models or to confirm appropriateness of simulations.
p. 30, section 2.6	Why wasn't data from Harmathy ("Properties of Building Material at Elevated Temperatures, NRCC 20956, March 1983) or data from Jeanes' (SFPE Technology Report 84-1, 1984) referenced for the BLAZE-SHIELD DC/F thermophysical properties? Jeanes report is based on his work while the AISI/NBS Research Associate. The thermal conductivities in this report are approximately 10% less than that determined by Jeanes, except at 1100 °C, where the current report notes the conductivity to be approximately twice that of Jeanes' data.
p. 31, section 2.6.2	The previous page provides the data collected for thermal conductivity. Why isn't a similar table provided for specific heat?
p. 31, section 2.6.3	Because the UL listings for BLAZE-SHIELD address the density of the material using an "untamped" sample, how was the density measured that is reported in this paragraph?
p. 32, sect 2.6.4	We recommend providing the obtained here.
p. 32, section 2.7, penultimate sent	ASTM E760 could be consulted for performance criteria.
p. 32, sect 2.7.1, 2nd sent, 1st para	What strength is referred to here? Adherence? Coherence? Other?
p. 33, section 2.7.2, 1st sent	What criteria were applied to judge acceptability?
Page 34, section 2.7.3 and Table 2-4	These areas note that the adhesive strength of the SFRM decreased considerably when applied over primer paint. The specific primer paint used in the test, and at WTC if known, should be noted, as well as whether

	or not it was one recommended for use by the SFRM manufacturer. When primer paint is used, it must be compatible with the specific SFRM used. Primer paints are generally not required, but it is required that the steel surface be free of dirt, oils or loose mill scale. As tests noted in this document confirm (see page 34, second to last paragraph), adhesive strength can sometimes be negligible when primer paint is used. This is evidenced by test data for other locations. In the tests done for this study, "Two-thirds of the samples with the thicker SFRM had no adhesion to the coated steel plates." In Table 2-4, for the 1-1/2 in. thick samples with primed steel, the standard deviation is considerably higher than the average. This issue is covered in Rec. 6 on page 206 of NCSTAR 1, but it would seem that the presence of primer paint on the structural steel at WTC may have been as significant a factor as debris impact. This was not obvious in the summary report and should be elaborated on in the "Findings" section.
p. 37, section 3.1.1, line 6	The innovative nature of the floor system seems to be provided as an excuse for the inadequate behavior or lack of testing. Innovative systems are often the subject of testing. Systems that have been used for many years and that have already been tested do not need to be the subject of additional tests. Innovative or not, a fire resistance test should have been performed on a prototype (that was the common practice at the time, as identified in the 2nd sentence of section 2.1).
p. 39, next to last line	"Flame spread" has a specific meaning in the fire protection field, meaning propagation of a flame along a solid surface. In the context of fire resistance considerations the typical terms used are "flame propagation" or "fire spread". (see also: p. 43, 3rd line)
p. 40, section 3.3.3, 2nd sent	How does the referenced report, published in 2002, provide an indication of furnaces available in 2004?
p. 45, last line of para 2	The ratings are included in section 3.6.2, not 3.6.1
p. 58, sect 4.1.1, para 2, last sent	What was the basis for the estimate of the concrete strength in the WTC slabs?
p. 60, 1st bullet of section 4.1.2	What is the basis for the property data? The noted reduction in the modulus of elasticity is much greater than that reported in ASCE Manual 78 (Lie, *Structural Fire Protection*, 1992) which indicates that a conservative estimate is about 50% (not 75%). In this publication, Lie's use of the word conservative means that the greatest that the strength would be reduced is 50%. Buchanan indicates a similar proportion. Many times, mechanical data at elevated temperatures includes creep behavior as an integral part of the measurement? How were creep effects isolated in the data reported here?
p. 61, 1st bullet	What is the basis for the property data? The noted reduction in the yield strength is much greater than that reported in ASCE Manual 78 (Lie, *Structural Fire Protection*, 1992) which indicates that a conservative estimate is about 38% (not 80%). Harmathy (NRCC 1993 publication cited previously) indicates a reduction of about 44%.

Page 63, Figure 4-3	What is the basis for the property data? No reference is cited, nor is any indication provided to suggest that this data is a result of research conducted as part of this study.
Page 69, section 4.2.2	One area which has not received as much attention as necessary is the type of connection between the floor trusses and the surrounding structure. It appears that the connections were originally designed only for vertical loads without consideration for the tensile forces which could occur in fire conditions. The actual tensile forces could have been greater if the fires had occupied only one floor of the building, leading to possible tensile failures and progressive floor collapse. It is shown that they have limited strength in both the vertical and horizontal directions. Determination of the horizontal forces on these connections results from a complex interaction between the floors and perimeter frame, which has not been analyzed in as much detail as possible. The main item missing is a proper analysis of the magnitude of pull-in forces through the full development of fire, including the cooling phase. The full floor subsystem analyses (Section 7.3) are based on boundary conditions assumptions which are not accurate because these depend strongly on the horizontal stiffness of the supports which in turn depend on the behavior of the floors above and below the fire floor. Because this interaction was not properly evaluated, the exterior wall subsystem analysis (Section 7.4) had to be based on an assumption of a constant horizontal force which was evaluated empirically in order to match the failure conditions. The global model (Chapter 8) had to be based on further assumptions deduced from the above incomplete sets of analyses. This is not a major criticism, because a more detailed analysis would have been more complicated and would probably have not resulted in any different conclusions. An advanced structural analysis such as this requires a judicious balance between simplicity and complexity, and that balance seems to have been set at about the right level considering the accuracy of the input data and the need to get realistic answers in a reasonable time.
p. 87, group of bullets	Are the noted temperatures relative to the scenarios considered in this incident? If so, it should be noted what conditions each of the temperatures are relevant to. If they are randomly chosen to demonstrate behavior of a range of temperatures, that should be noted.
p. 150, line 1	Define "conservative".
p. 186, last sent of 2nd para	Case A is identified as being correct for one aspect, and case B for another. These are two significantly different cases. Which is to be believed?
p. 192, line 8	Concerning the concrete material model, assuming the same strength in

	tension and compression means that only 3 ksi can be carried in tension?
p. 196, 2nd para, last sent	If there was only a modest reduction in stiffness, how did the deflection increase to 37" on that side?
p. 196, 3rd para, 2nd sent	Vertical deflection was found to be insignificant, but the south side experiences major deflections per Table 7-1.
p. 196, 3rd para, 6th sent	"Restraint" is the more common term instead of "constraint"
p. 197, Tables 7-1 and 7-2	Several of the maximum displacements noted occur 10 minutes after aircraft impact, implying that the displacement decreases with fire exposure. This is surprising given the decline in the modulus of elasticity and creep effects. This is also contrary to the visual observations of increasing sag in floors and may be an indication of the source of the underestimation in floor deflections noted on p. 222 (see below).
p. 216, paragraph	Is this description absolutely the only mechanism possible to achieve the inward movement? Wouldn't heating from a fire exposure on only the inside cause the same effect, though maybe not for the magnitude observed? Could uneven heating contribute to overestimation of the pull-in forces? There's no evidence that the heating from a 1-sided fire exposure was considered.
p. 222, 2nd bullet, last sent	Given that the floor sagging was greater than that predicted, is it possible that neglecting cracking and spalling was significant, and should have been considered in the simulation?
Page 237, Figure 8-13	How does the predicted displacement compare with observations?
p. 272, 3rd bullet	The reference to the standard test is inappropriate. As indicated earlier in this report, the standard test is a comparative test. It cannot be used to predict performance from an actual fire in any way. A 15-minute fire from actual commodities has been observed to induce greater temperatures in steel members than a 3-hour fire exposure following the standard test procedure (see Seigel, *Fire Technology*, Nov 1970).

Comments on NCSTAR 1-6B

Location	Comment
Page 2, section 1.3	In this section, NIST infers that it has identified the important test variables and those are (1) fireproofing thickness, (2) constraint conditions, and (3) scale of the test. What NIST has missed is the most important variable in fire resistance testing, that being the difference in heating conditions. While ASTM E-119 specifies a standard temperature versus time profile, ASTM E-119 does not specify a standard heating profile. While the temperature indicates a potential for heating of a test specimen, it does not define the heat exposure to the specimen. Heating conditions can vary significantly from test to test within a particular test furnace (repeatability) and even more significantly from furnace to furnace (reproducibility). Tests performed on the larger ULC furnace might not be comparable to a similar test on the smaller UL furnace even though the same temperature versus time profile is reproduced. The measured temperature within a furnace is not a reliable measurement of the heat flux produced in the furnace. Heat flux drives the response of the specimen being tested. The size and geometry of the furnace, the thermal inertia of the furnace lining, and the emissivity of the furnace gases will greatly influence the heat flux that is experienced by the specimen. Kanury and Holve concluded (Kanury A. M., and Holve, D. J, <u>A Theoretical Analysis of the ASTM E-119 Standard Fire Test of Building Construction and Materials, Menlo Park, CA, Stanford Research Institute, 1975):</u> "Radiant heat transfer is the dominant heat transfer mode. Reradiation properties of the exposed material have an influence on the fire resistance time. Thus, the true measure of fire severity is given by the heat flux to the specimen, a function of both the furnace temperature and emissivity. The exact temporal distribution of temperature exposure has little effect on the fire endurance time as compared to the standard ASTM E-119 T(t) curve. Future improvements of the ASTM E-119 test should focus more on the control, measurement, and specification of the heat flux exposure condition rather than the furnace temperature history. Furnace emissivity has appreciable effect on endurance time, even though the relation is less than linear. An increase in emissivity from 0.2 to 0.6 increases the net flux by 80% and decreases the fire endurance time by 30%"

	We would suggest that Section 1.3, Test Variables, should be revised by NIST to indicate that all test variables have not been identified and isolated. The most significant variable in fire resistance testing is the heat flux in the furnace. The different heating conditions between the two test furnaces used in this evaluation have not been identified or analyzed.
Page 44, section 4.5	The report describes radiometers used to measure and characterize the furnace environment during the tests. It states that the location of the radiometers is given in Appendices D and F. However, the location of the radiometers is not clearly indicated in those Appendices. Pages 45 - 46 describe the instrumentation. For the most part, standard Type K pipe-shielded thermocouples were used for furnace control and information. In addition, plate thermocouples and aspirated thermocouples were placed on the bottom cord of main trusses (in part) and in the valleys (in part). Additionally, a few Gardon Gauges and Schmidt-Boelter gauges were provided. We recommend that the report include complete data output for the instrumentation, so that a more detailed investigation for the differences between the ratings obtained for the 17 and 35 foot assemblies could be conducted.
Page 95, section 6.1	The average furnace temperatures, as measured by the ASTM E-119 standard thermocouples, are shown. While this demonstrates that the furnace temperatures measured in the four tests were comparable, it does not demonstrate that the heating conditions were similar.
Page 96, section 6.1.2	Section 6.1.2, Furnace Temperature Environment, indicates that additional instrumentation was included to "further characterize the thermal environment of the exposing fire." While the measurements from the thermocouples reflect the temperature conditions in the furnace, the true thermal environment can only be assessed with the reporting of the heat fluxes measured by the radiometers. NIST failed to report the radiometer measurements in this section. Complete data from the radiometers should be reported in this section. Some, very limited information about furnace heat fluxes is reported, in part, in Chapter 5, Test Results. This information can be found only in Figures Nos. 5-11, 5-12, 5-48, 5-49, 5-64, and 5-65. This information is summarized below: <u>Test 1 ULC, 35 ft., Restrained</u> West Radiometer Heat Flux Range: 10-50 kW/m^2 Mean Flux: 20 kW/m^2 (estimated) East Radiometer Heat Flux Range: 10-60+ kW/m^2 Mean Flux: 40 kW/m^2 (estimated)

	<u>Test 2 ULC, 35 ft., Unrestrained</u> No radiation data reported <u>Test 3 UL, 17 ft., Restrained</u> South Radiometer Heat Flux Range: 20-135 kW/m^2 Mean Flux: 90 kW/m^2 (estimated) North Radiometer Heat Flux Range: 20-110 kW/m^2 Mean Flux: 70 kW/m^2 (estimated) <u>Test 4 UL, 17 ft., Unrestrained</u> South Radiometer Heat Flux Range: 5-40 kW/m^2 (prior to failure) Mean Flux: 25 kW/m^2 (estimated) North Radiometer Heat Flux Range: 20-100+ kW/m^2 Mean Flux: 95 kW/m^2 (estimated) There is clearly a significant difference in heating conditions between the ULC and UL furnaces despite the fact the both furnaces followed the same temperature versus time curve. Such a large difference in heating conditions would have a considerable effect on the response of the tested specimen. Figure 6-2 infers that the heating conditions between the two furnaces were similar. The data for two plate thermocouples were plotted only for Tests Nos. 2 and 4. Similar data for Tests Nos. 1 and 3 were not given or plotted to show correlation. Figure 6-3 clearly shows a significant difference in recorded temperatures for the south plate thermocouple in the range beyond 50 minutes. The lack of correlation among all of the plate thermocouples and the radiometers in the four tests on two different furnaces is unexplained and unresolved. The limited data based on three thermocouples, ignoring the non-corroborative data of one thermocouple and the wide variation in readings from the radiometers, does not support the conclusion in Section 6.1.2 that "The ASTM E-119 fire exposures for both furnaces used in this study were essentially equivalent." There is an attempt to infer that the heating exposures in the two furnaces were identical based on incomplete data and without mention or explanation of the variation in radiometer data. Based on the radiometer data, one cannot reasonably conclude that the heating conditions were identical even though the temperature profiles for two of the plate thermocouples are similar. NCSTAR 1-6B should provide some rational explanation for the discrepancies in data between the two furnaces or revise the statements about similar heating conditions in the two furnaces. There is a large difference in the thermal exposures between the large scale ULC tests and the smaller scale UL tests. The results of the tests on the

	two furnaces are not directly comparable. The NIST report fails to recognize or report on the difference in test conditions. The NIST report should clearly indicate the difference in heating conditions among the tests and comment on the lack of correlation between the ULC and UL tests. Comment on the fact that the specific, single tests performed for this investigation are neither repeatable nor reproducible would be appropriate.